Low Density Materials

Date: 03 07 2013

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Program Officer

AFOSR/RTD

Air Force Research Laboratory

Integrity ★ Service ★ Excellence

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2013 AFOSR SPRING REVIEW

NAME: **Low Density Materials**

PORTFOLIO DESCRIPTION :

Transformative research targeting advanced materials that enable substantial reductions in system weight with enhancements in performance and function.

INCREASING SPECIFIC PERFORMANCE

(performance/pound)

PORTFOLIO SUB-AREAS:

Structural Lightweighting →

Multifunctionality ↗

Materials By Design ↑

Increased emphasis on forging interdisciplinary teams to address broad-base challenges

Why Low Density Materials?




If it has structure and rises above the ground, material density is important!




Material density impacts: payload capacity, range, cost, agility, survivability, environmental impact….

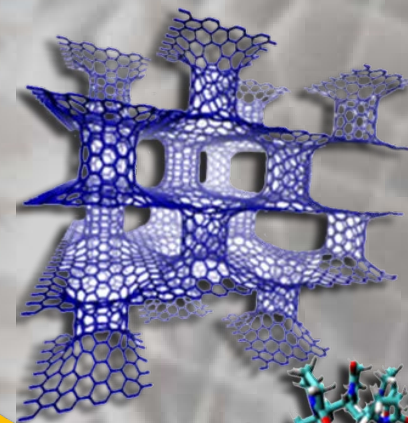
Research Thrusts

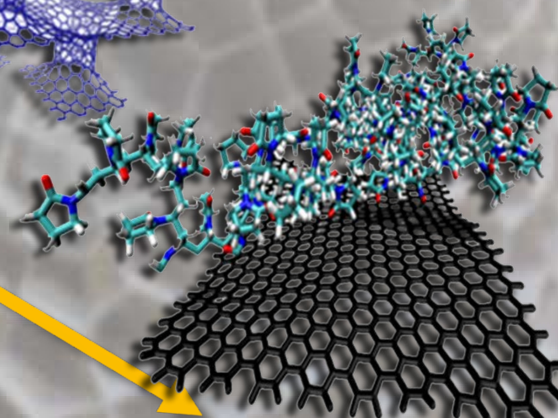
STRUCTURAL LIGHTWEIGHTING

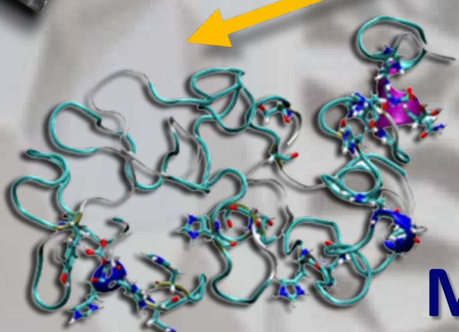
- taking the weight out of traditional composites

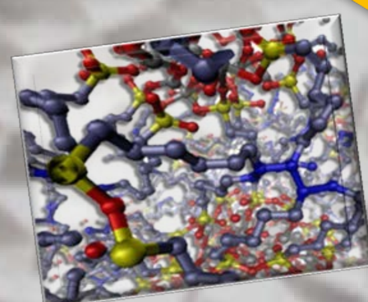
MULTIFUNCTIONALITY

- coupling structure + function









MATERIALS BY DESIGN

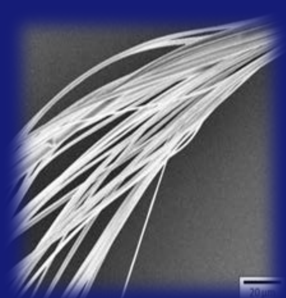
- bottoms-up materials design based on structural requirements

Structural Lightweighting Highlights

Nanomaterials for Aerospace Structures

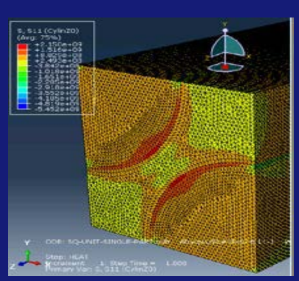
Translating the revolutionary properties of nanostructured materials to macroscale load-bearing structures

- Signed Memorandum of Agreement with NASA LaRC
- Nanotube Assemblages for Structures Workshop, April 2012
- Established working group to develop coordinated interagency roadmap for structural nanomaterials

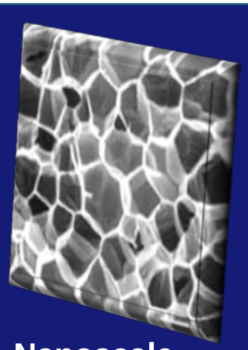


Improved Fibers & Resins

Nanotechnology



Predictive Modeling



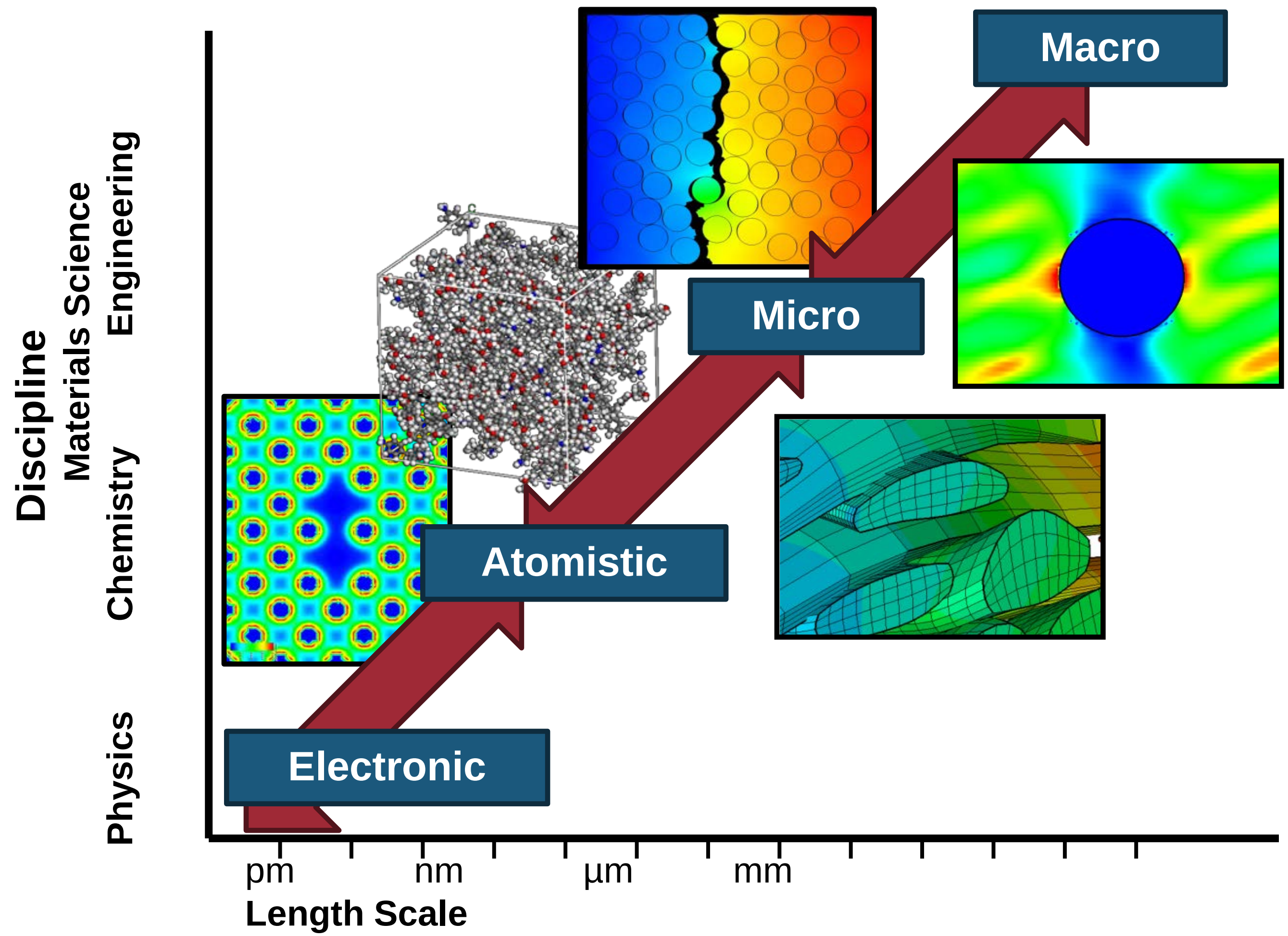
Nanoscale Porosity

Materials By Design

Design the structure based on limitations of the material

Design the material based on structural requirements

Connecting Atomistic & Microscale Behavior -- Essential for Materials Design



Dr. Tim Breitzman
AFRL/RXBC

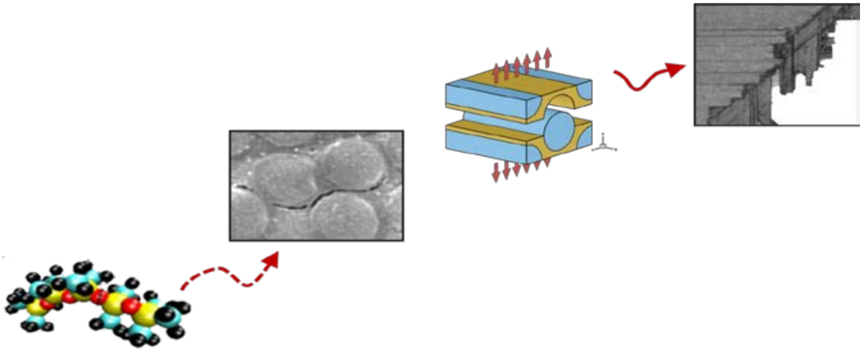
Dr. Rajiv Berry
AFRL/RXBN

Prof. Jim Moller
MIAMI UNIVERSITY

Connecting Atomistic & Microscale Behavior -- Essential for Materials Design

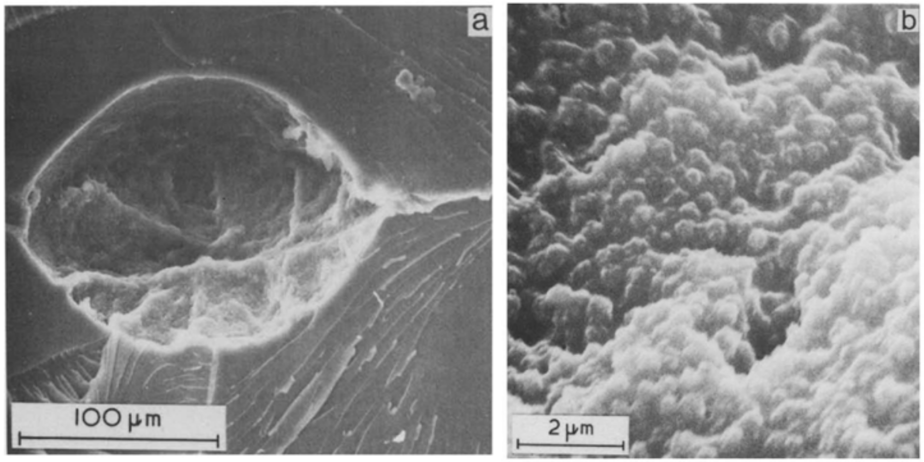
Goals

- Derive resin fracture toughness from atomistic behavior
- Integrate atomic & molecular simulation methods into materials system analysis



Fundamental Scientific Challenges

- No direct knowledge of fracture nucleation



(Morgan, Mones, Steele, Polymer, 1982)

Limits - Current Practice

- Unrealistic methods used to represent strain rate
- Bond scission not considered or permitted via a force field parameterized for other contexts
- Toughness properties in continuum scale based on empiricism

Novel Approach

- Strain-rate-controlled deformation
- Bond scission in covalently-bonded glassy polymer systems via Quantum Mechanics
- Detailed post-processing

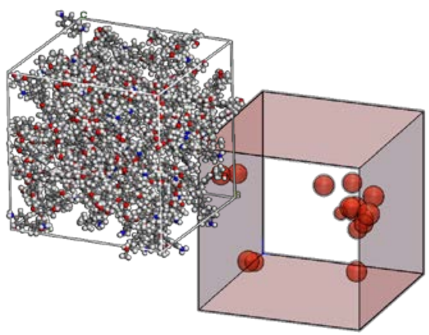
Integrated Quantum Mechanics-based Bond Scission with Molecular Dynamics

Technical Approach

• Quantum mechanical (QM) simulation of highly-strained zones

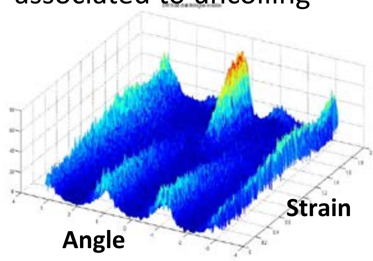
• Bond scission during deformation

• Unique analysis of molecular re-conformation dynamics & free volume development



Free volume clusters in molecular system

Chain backbone dihedral angle associated to uncoiling



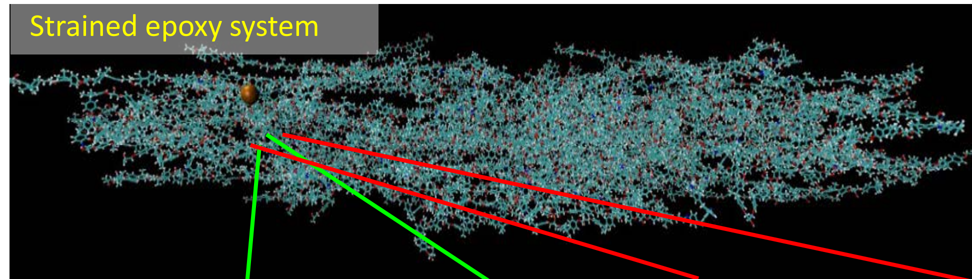
Impact

• Improved understanding of the origins of fracture: captured subatomic, molecular, & nanoscale events at nucleation.

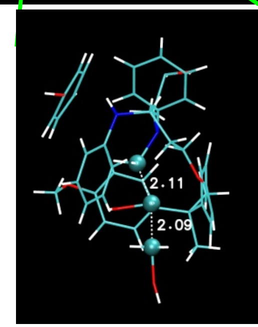
• Effect of resin formulation on nucleation.

• Information for micro-mechanics

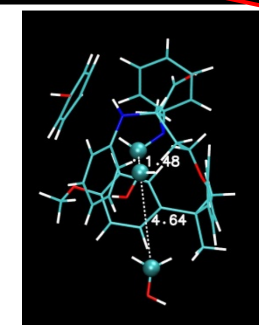
Accomplishments



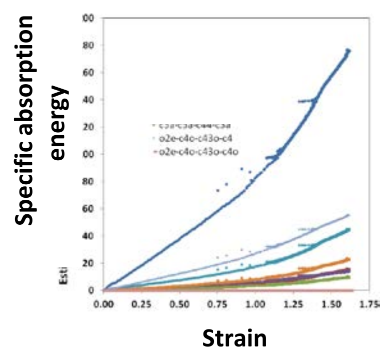
Before Scission

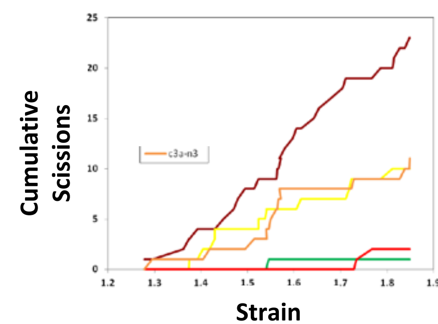


After Scission



Segments of molecular network absorbing mechanical energy

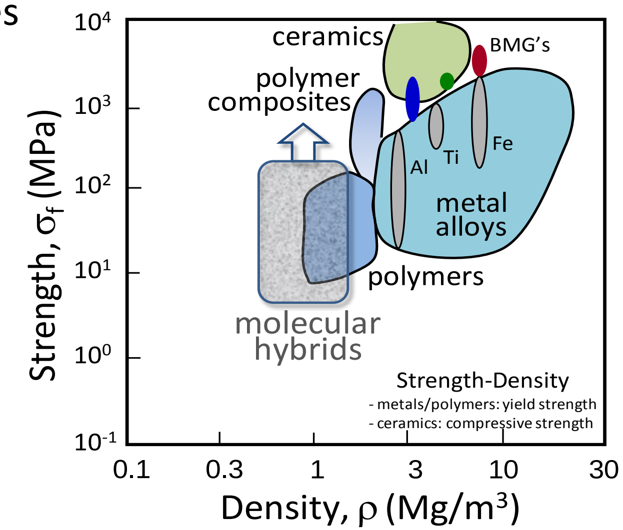


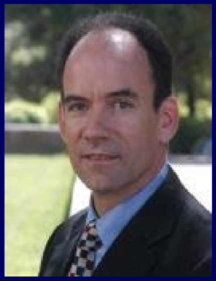


Weak points of the cross-linked network

Molecular Design of Hybrid Materials

- Molecular hybrids exhibit the lowest densities with the potential for significant increases in strength and toughness properties
- Organic and inorganic components from molecular to macro length scales enables mechanically-robust materials with multifunctional property sets
- Opportunity to tailor mechanical, thermal, electrical, and optical properties



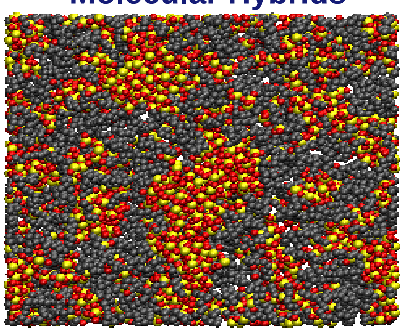


Prof. Reinhold Dauskardt

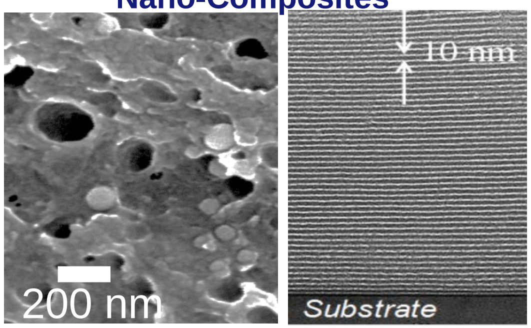
- Fellow of ACerS and ASM
- Recipient of Maso, IBM, SIA, and *TMS Awards for fundamental contributions to structural and electronic materials*

STANFORD MATERIALS SCIENCE AND ENGINEERING

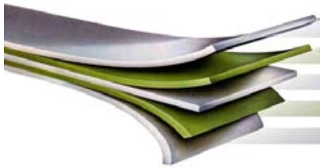
Molecular Hybrids



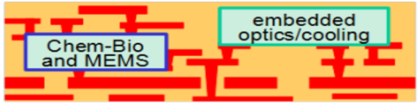
Porous Hybrids and Nano-Composites



Hybrid Laminates



Multifunctional Devices

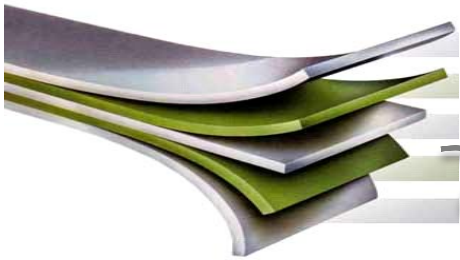


Å — 10 nm — 100 nm — 1 mm — 100 mm — 1 mm

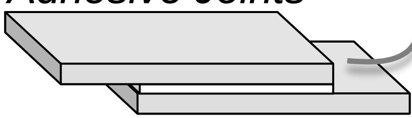
Bottom-Up Design of Multifunctional Hybrid Materials

Molecular Hybrid Design: High Performance Bonding

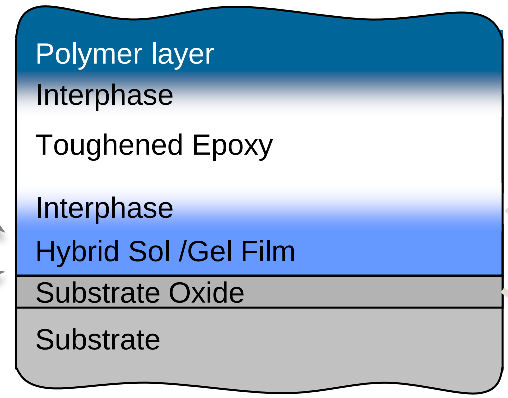
Performance Laminates



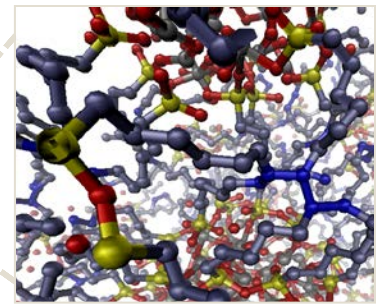
Adhesive Joints

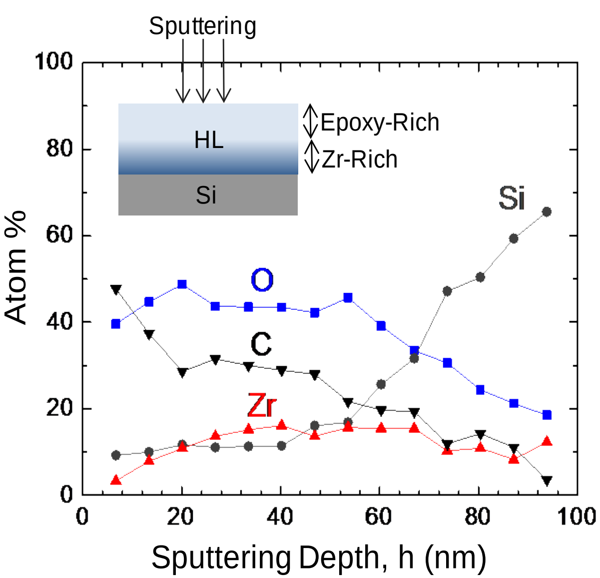


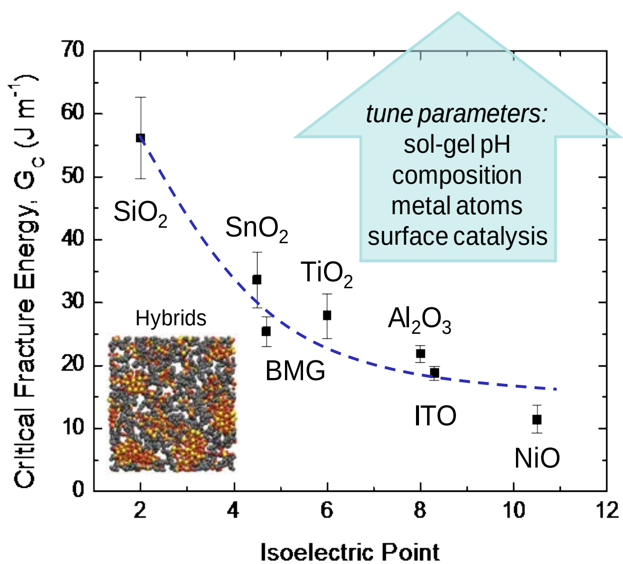
Interphase Region

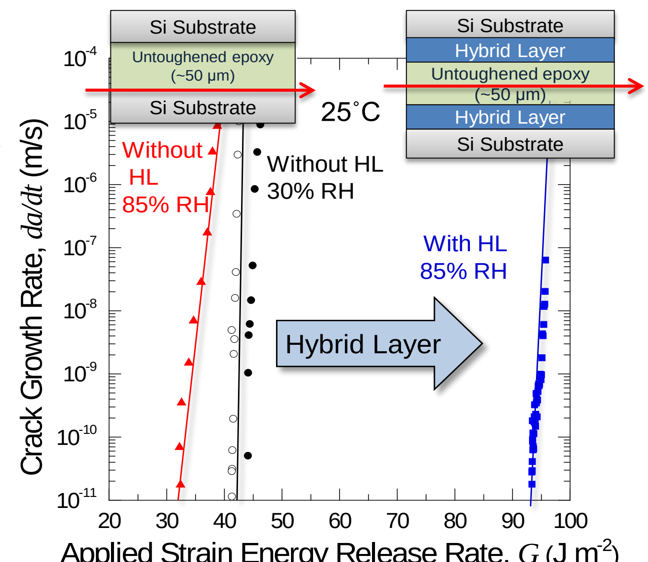


Hybrid Molecular Hybrid Sol / Gel Layers

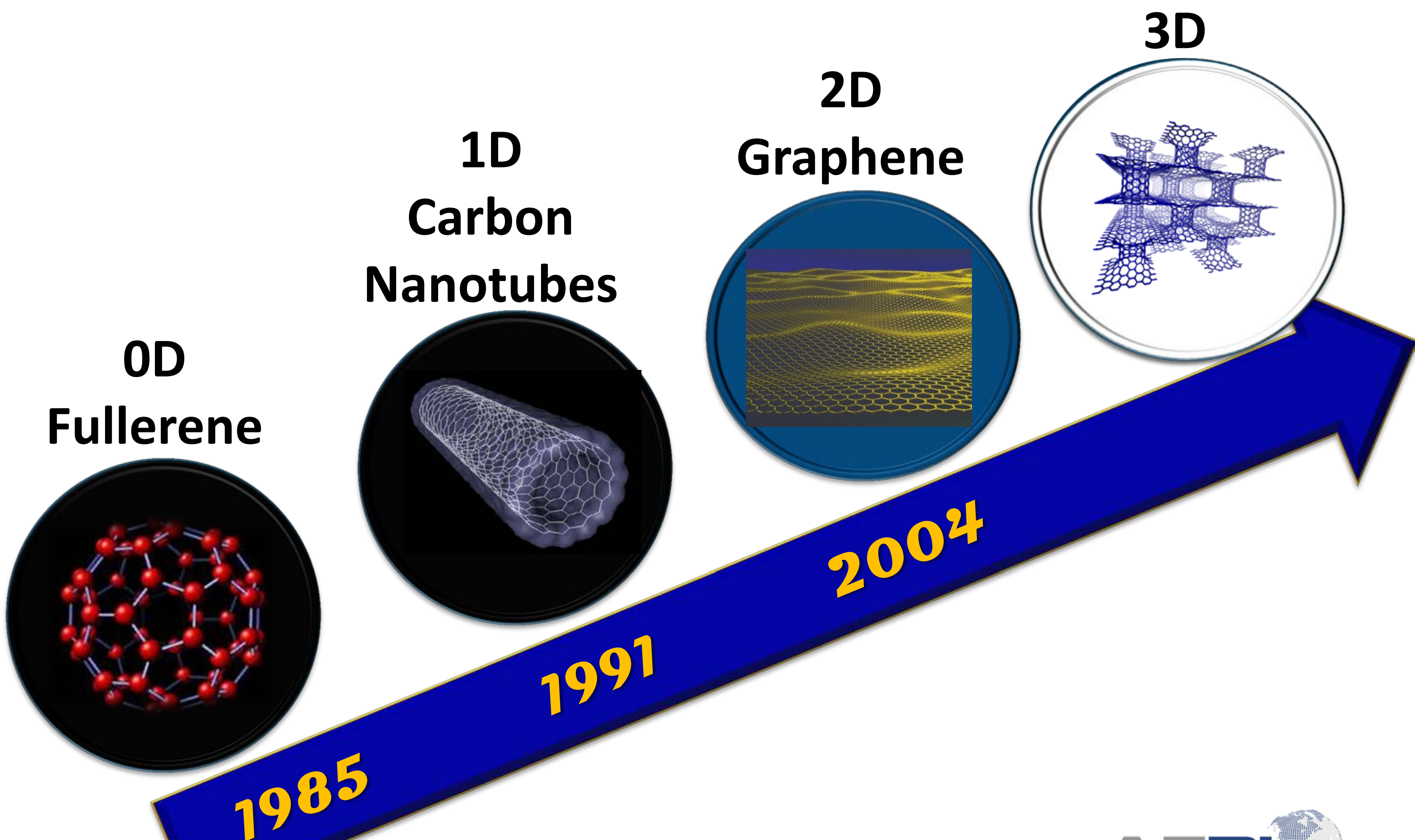




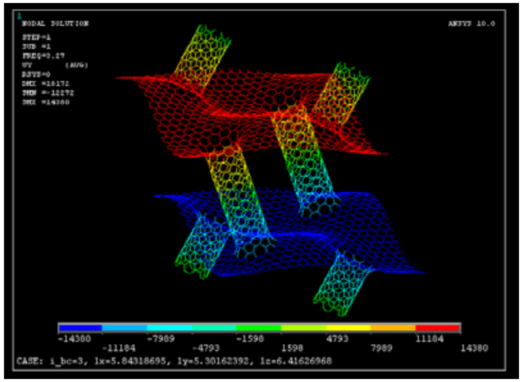


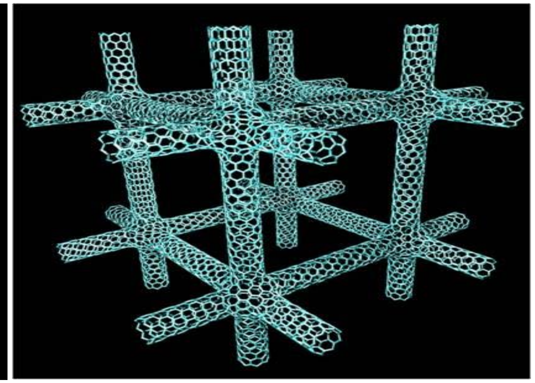


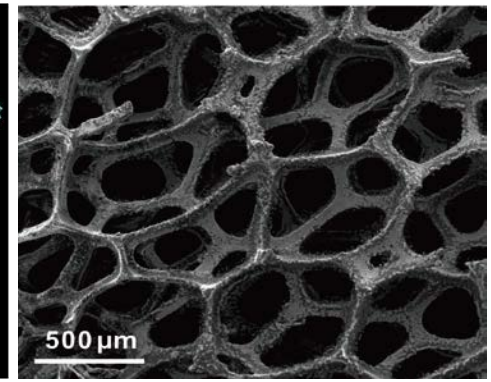
Nanostructured Carbon



MURI 11: Nanofabrication of 3D Nanotube Architectures







Overarching Scientific Challenges

- Covalent junctions between building blocks leading to 3D networks
- Systematic characterization/modeling of the junctions and properties
- Development of scalable growth processes for 3D nanostructured solids
- Structure-property correlations of mechanical and transport properties

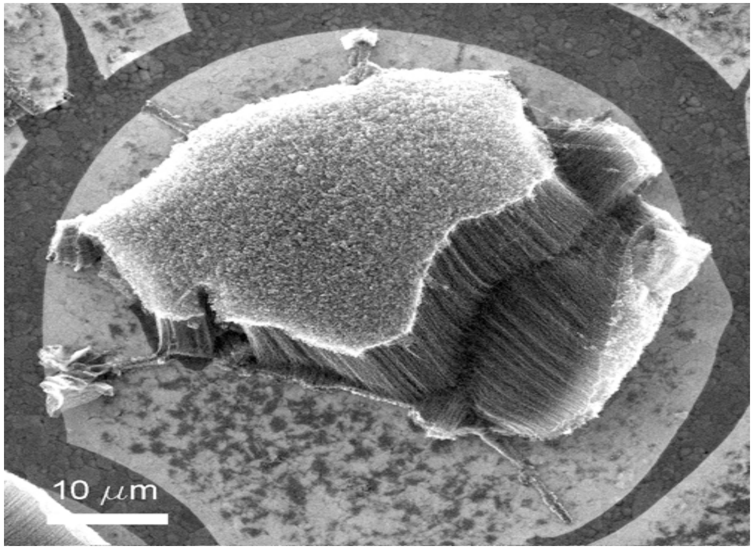
Potential Payoffs

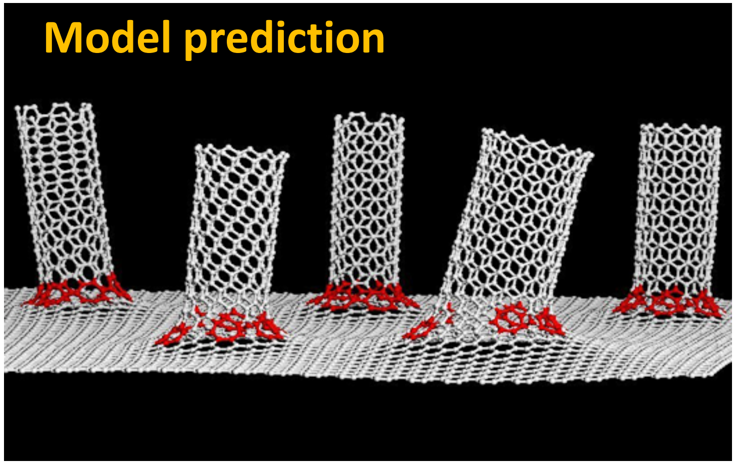
- Translation of exceptional 1D and 2D properties of tubes and sheets to 3D
- High surface area for energy storage and conversion devices
- Orthogonal transport of phonons for thermal management
- Mechanical reinforcement

Rice U. MURI Team 2012 Highlights

Towers of nanotubes sprout from graphene

(Futurity, Sci. and Technology, Nov. 27, 2012.)
(Nature Communications, 3:1225 doi: 10.1038/2234 (2012))

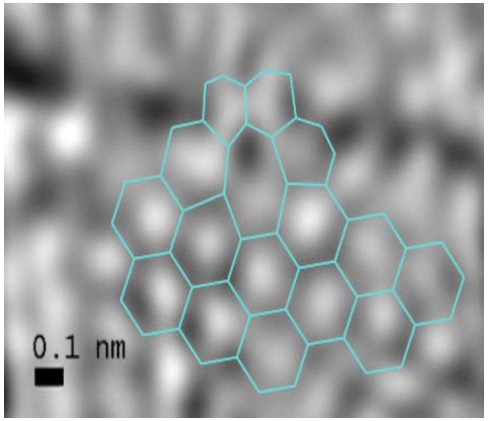


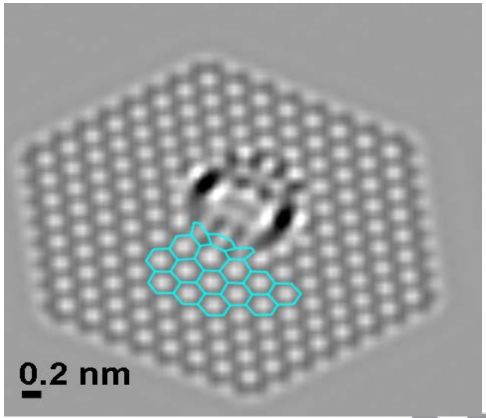


7-atom rings at the graphene-nanotube junction creates a seamless conductor

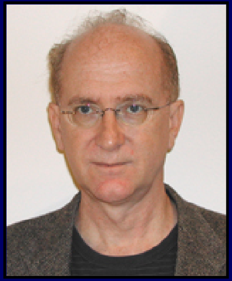
Surface area > 2,000 m^2/gm

Comparison of simulated and experimental STEM images illustrating covalent bonding between CNTs and graphene





Prof. James Tour

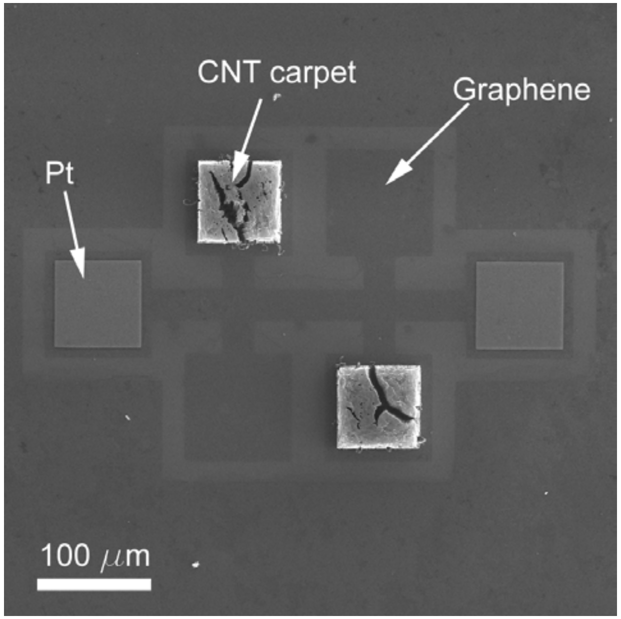


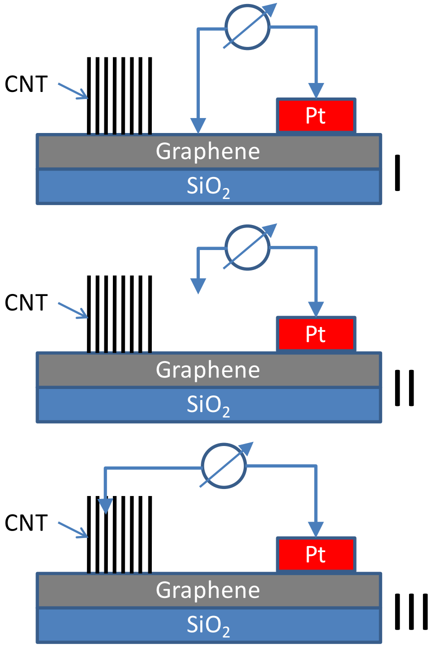
Prof. Boris Yakobson

Rice U. MURI Team 2012 Highlights

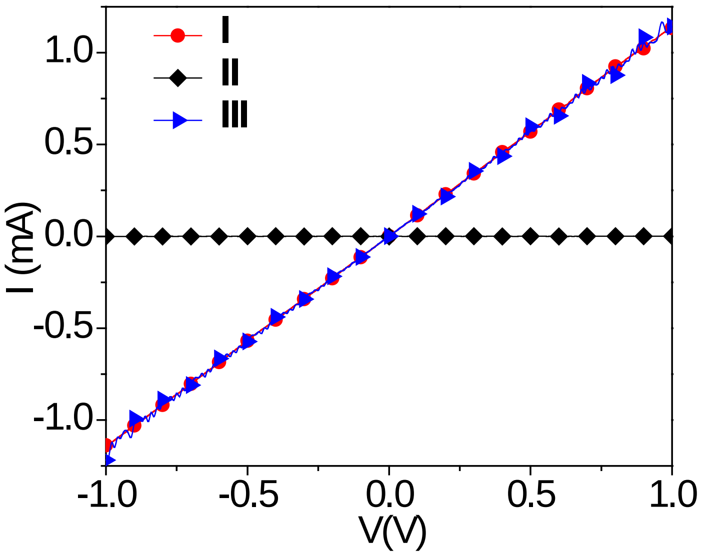
Electrical properties of the 3D CNT/graphene nanostructures

(Nature Communications, 3:1225 doi: 10.1038/2234 (2012)**)**



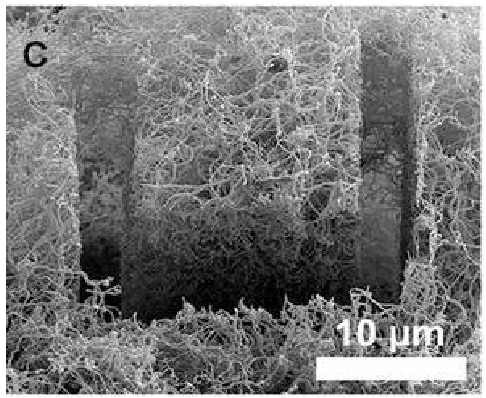


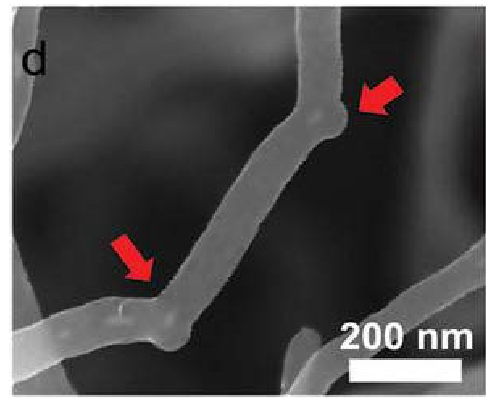
Ohmic contact at CNT and graphene junctions

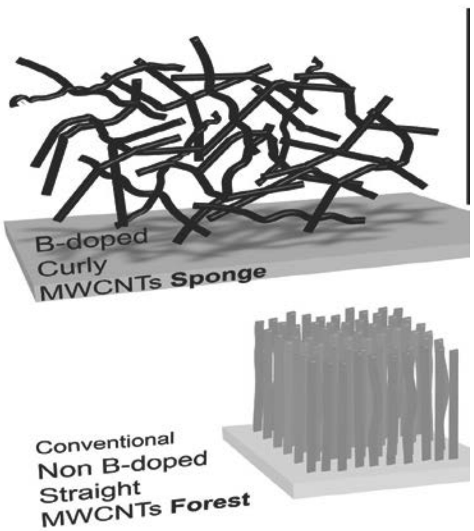


Rice U. MURI Team 2012 Highlights

3D Solids of Boron-Doped Nanotube Networks (CBxMWNT sponges)



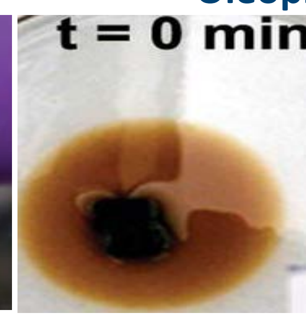


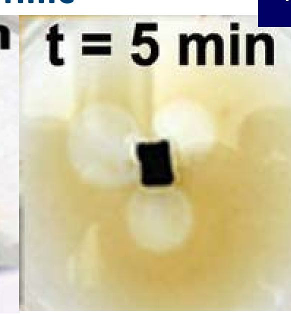


Covalent junctions established via boron doping led to novel properties

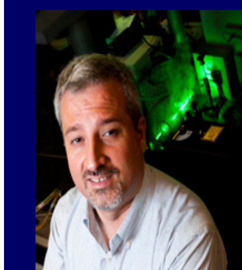
Hydrophobic

Oleophilic





Prof. P. Ajayan
Rice Univ.



Prof. Mauricio Terrones
Penn State Univ.

MURI Discovery Leads to Tech Transition

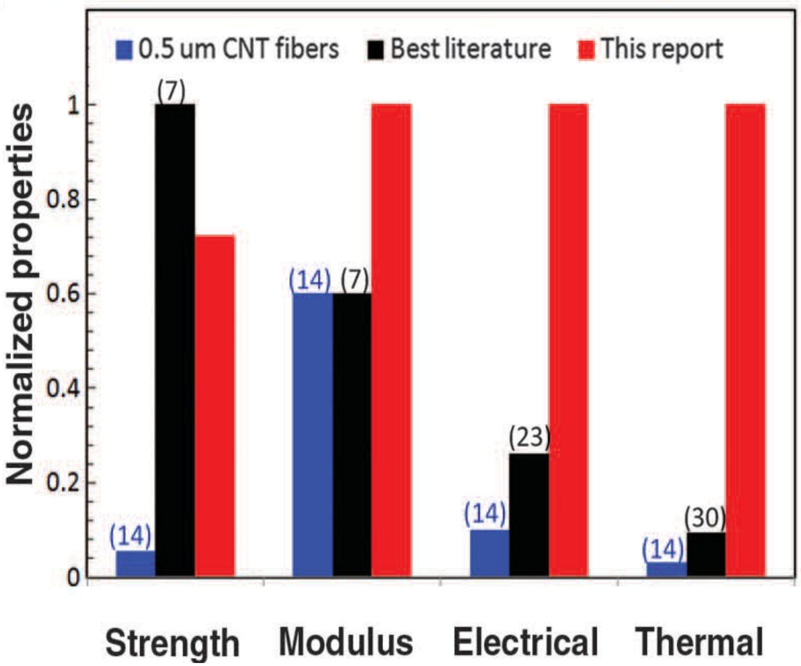
Carbon Sponge Solutions, Inc.

- Road to commercialization

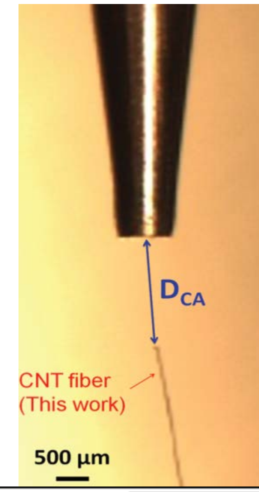
CSS, Inc. is a spin-off company out of Rice University (Houston, TX) founded in August 2012 (by student Daniel Hashim) with a mission to research, develop, and manufacture patent protected 3-D nanosponge products from the lab to the marketplace. Exploiting the nanomaterial's unique combination of multifunctional properties at both the nano-scale and macro-scale, many possible applications are expected for the environment, energy, and biomedical industries.

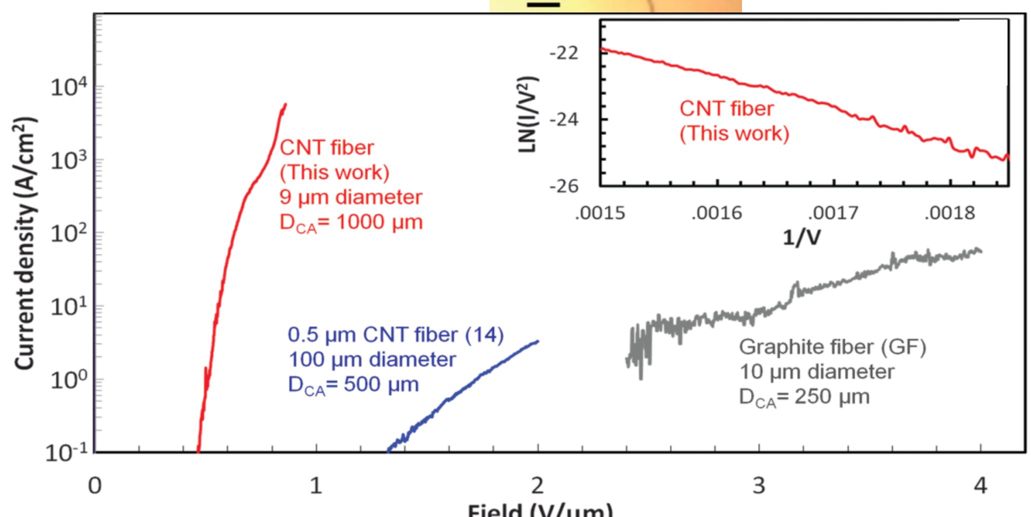
CNT Fiber Tech Transition

*"...high-performance multifunctional carbon nanotube (CNT) fibers that combine the **specific strength, stiffness, and thermal conductivity of carbon fibers** with the **specific electrical conductivity of metals**. "*
(**Science,** 11 January 2013: Vol. 339 no. 6116 pp. 182-186.*)*



Field Emission Studies





Prof. Matteo Pasquali

RICE

Tech Transition
- AFRL/RX
- Teijin Aramids

Basic Research Initiative

AFOSR/NSF Joint Research Solicitation

ODISSEI: Origami Design for Integration of Self-assembling Systems for Engineering Innovation

Advance understanding of folding and unfolding of materials structures across scales for design of engineered systems

Jointly reviewed and funded 8 grants totaling approx. $16M

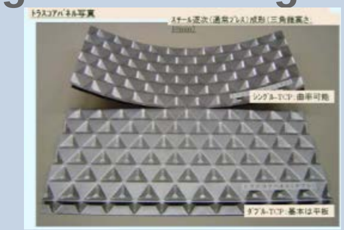
- **Synthesizing Complex Structures from Programmable Self-Folding Active Materials**, Richard Malak, Texas A&M U.
- **Mechanical Meta-Materials from Self-Folding Polymer Sheets**, Christian Santangelo, U. of Massachusetts Amherst
- **Photo-Origami**, Hang (Jerry) Qi, U. of Colorado at Boulder
- **Externally-Triggered Origami of Responsive Polymer Sheets**, Jan Genzer, North Carolina State U.
- **Programmable Origami for Integration of Self-assembling Systems in Engineered Structures**, Daniela Rus, Massachusetts Institute of Technology
- **Multi-field Responsive Origami Structures - Advancing the Emerging Frontier of Active Compliant Mechanisms**, Mary Frecker, Pennsylvania State U.
- **Uniting Principles of Folding and Compliant Mechanisms to Create Engineering Systems,** Larry Howell, Brigham Young U.
- **Multi-scale Origami for Novel Photonics, Energy Conversion**, Max Shtein, U. of Michigan Ann Arbor

Joint RX, RQ Labtask
Adaptive Origami for Efficiently Folded Structures

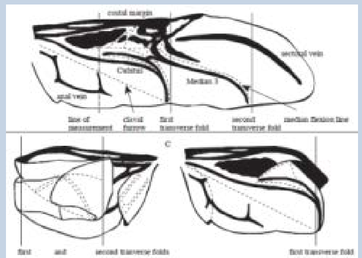
STRUCTURES	MECHANISMS

Aeronautics

Light and strong



Origami Honeycomb

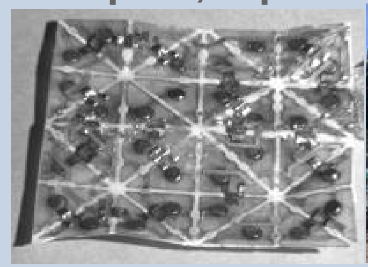


Wing folding

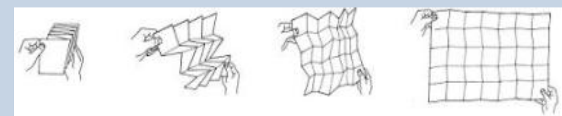
Shock absorbing structures

Aerospace

Compact, repeated pattern

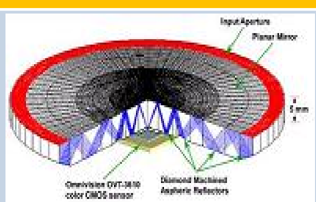


Self folding sheet

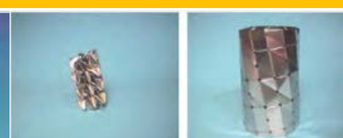


Deployable Solar sails, Antennas

Optics, Sensors, Energy Harvesting, Bio



Ultrathin, High-Resolution Origami Lens



Expandable stents

Solar origami

Research Team

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http://www.origami-resource-center.com/origami-science.html

Research Community Leadership

AFOSR

Low Density Materials

AFRL DIRECTORATES

RX, RV, RQ, RW
LRIRs, STTRs,
MURIs,
Workshops,
Reviews, Visits

DOD COMMUNITY

Reliance 21 Board Materials and Processing COI

INTERNATIONAL

US-India Tunable Materials Forum

US-AFRICA Initiative

OTHER AGENCIES

Lightweight Structures

Nanostructured Materials

Origami
2D Beyond Graphene

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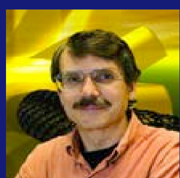
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Philip Bradford
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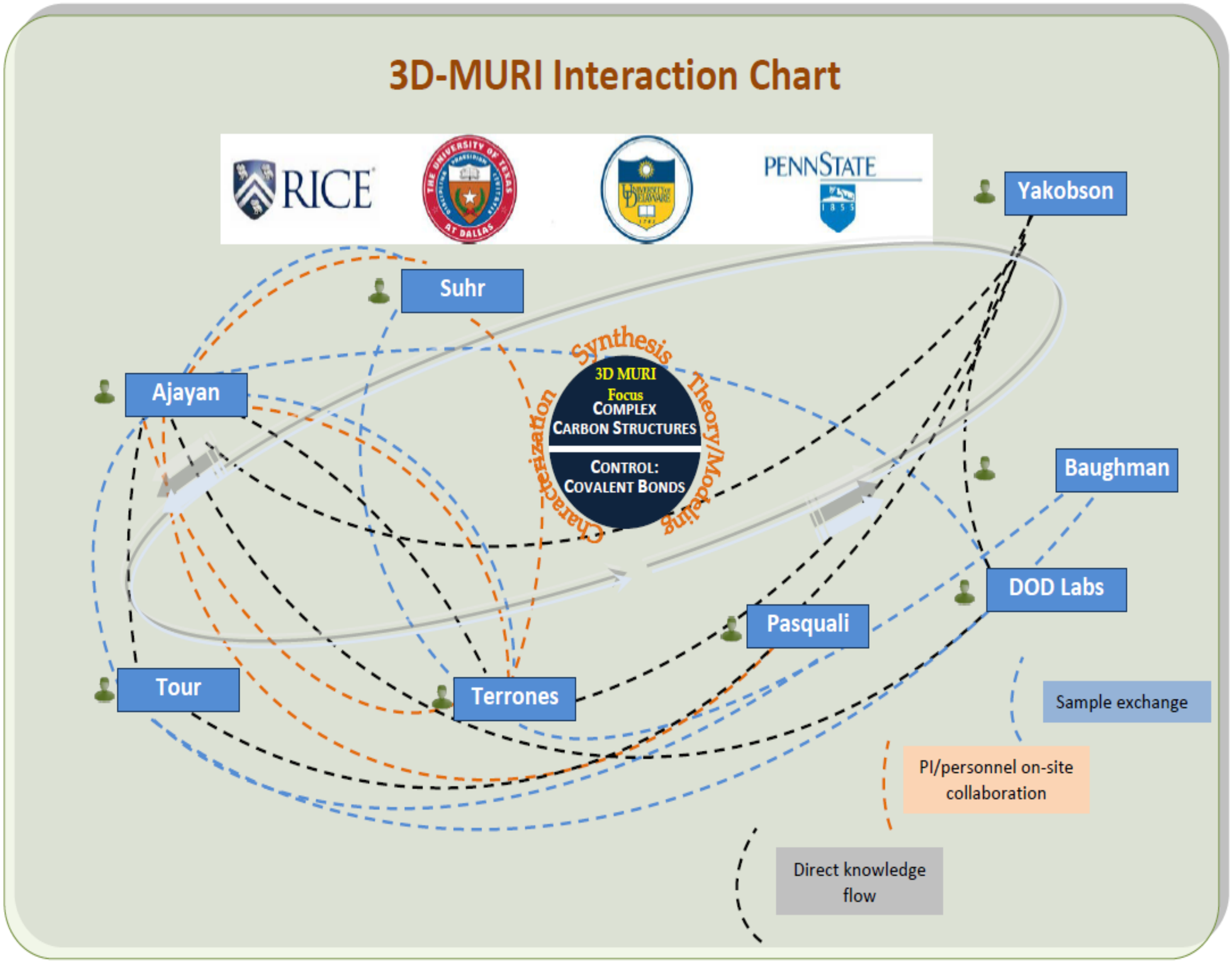
THANK YOU

Rice Univ. MURI Team: Strong Multidisciplinary Collaborations



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Hierarchical Organization in Materials Design

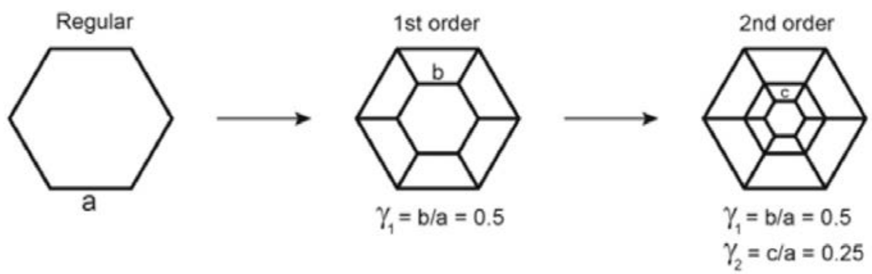
Goals

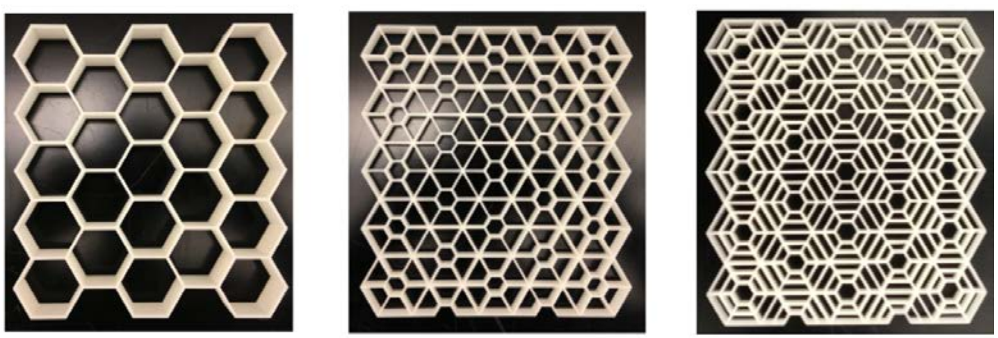
- Develop fundamental understanding of the role of hierarchy in controlling properties and functionality in material surfaces, interfaces and in cellular structures
- Analytical and predictive numerical models for studying the mechanical behavior of hierarchical honeycombs, composite lattice structures and bonded joints with non-flat interfaces

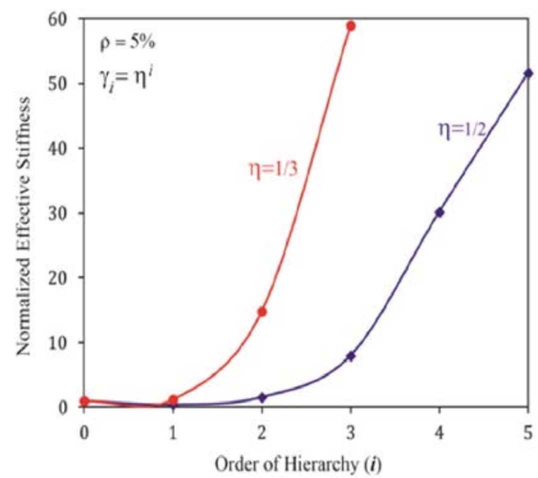
Prof. Ashkan Vaziri, Northestern Univ.

- AFOSR YIP Award

Self-similar Hierarchical Spiderweb Honeycombs with 1st and 2nd order hierarchy

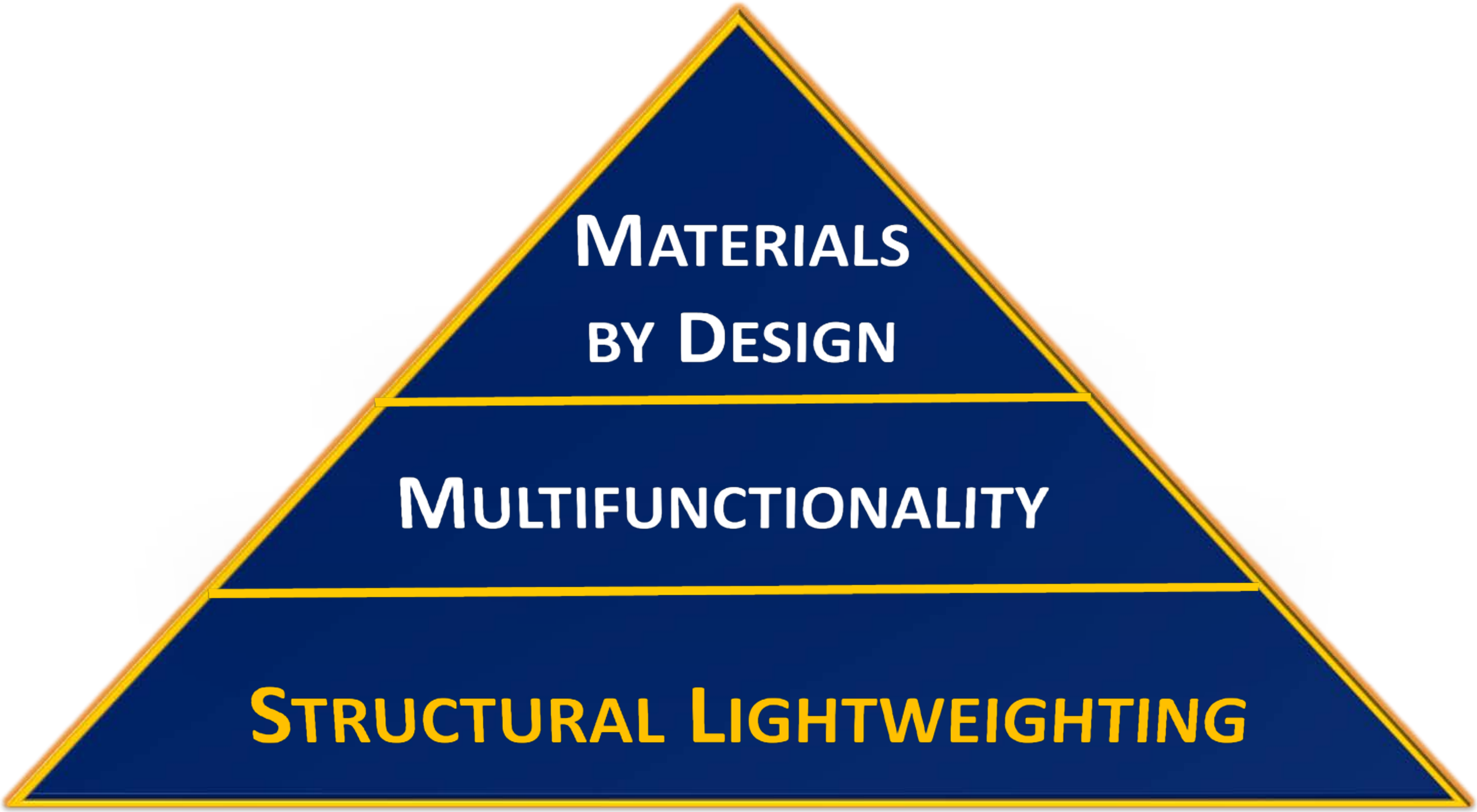




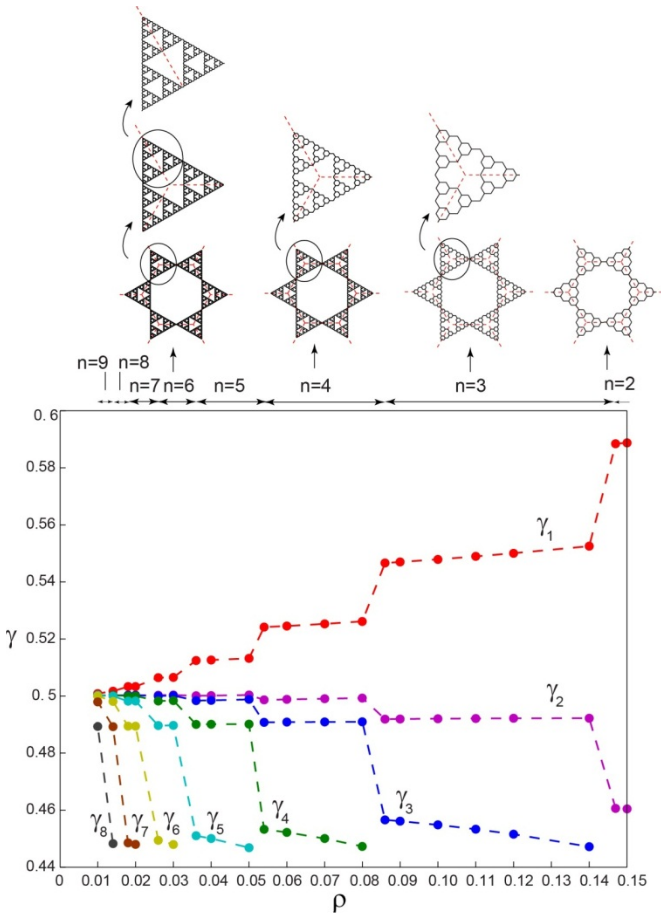


Numerical simulations show significant increase in the effective stiffness of spiderweb honeycombs compared to regular honeycombs of the same mass/density

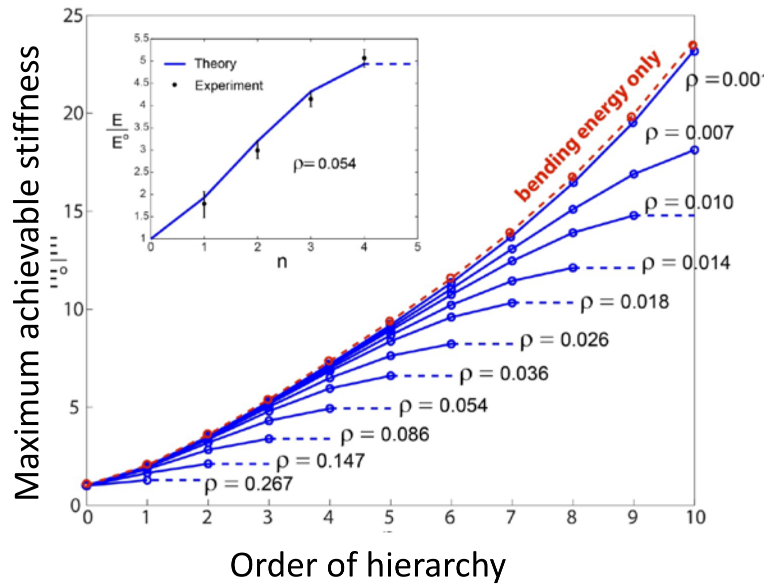
Increasing Specific Performance in Aerospace Platforms



Self-Similar Hierarchical Honeycombs



Optimum topology of hierarchical honeycombs, which approaches the fractal limit.

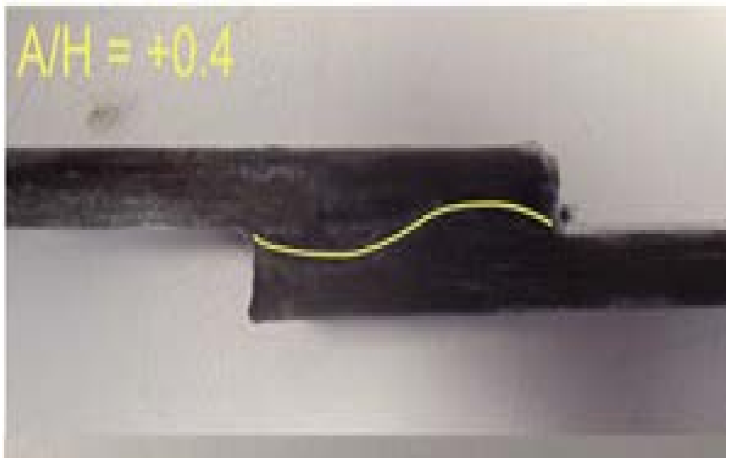


n=3

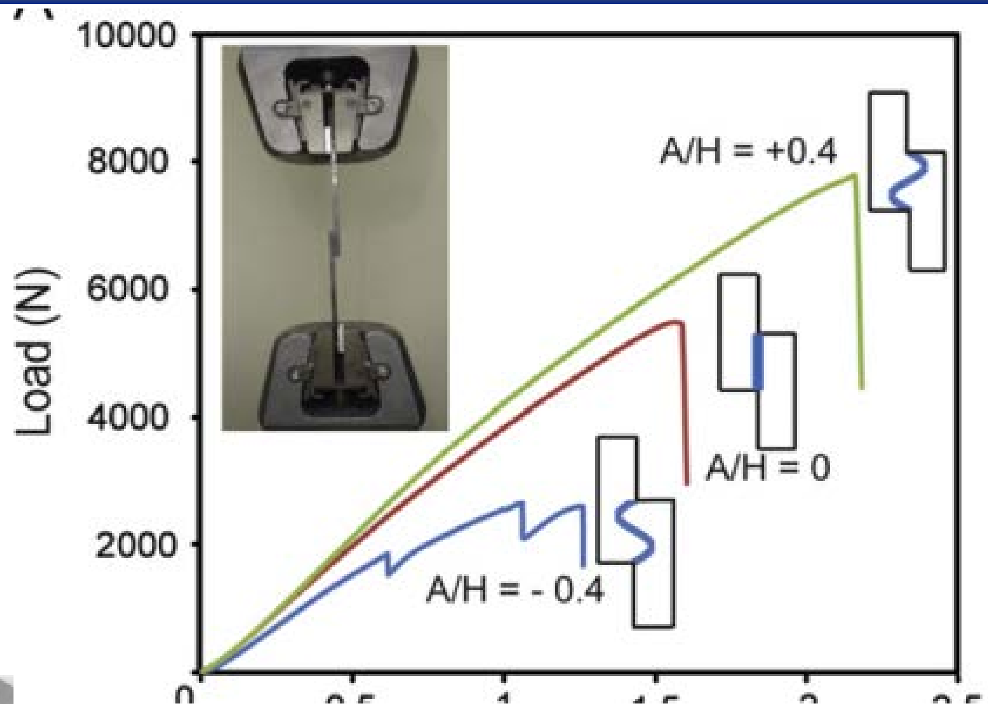
n=4

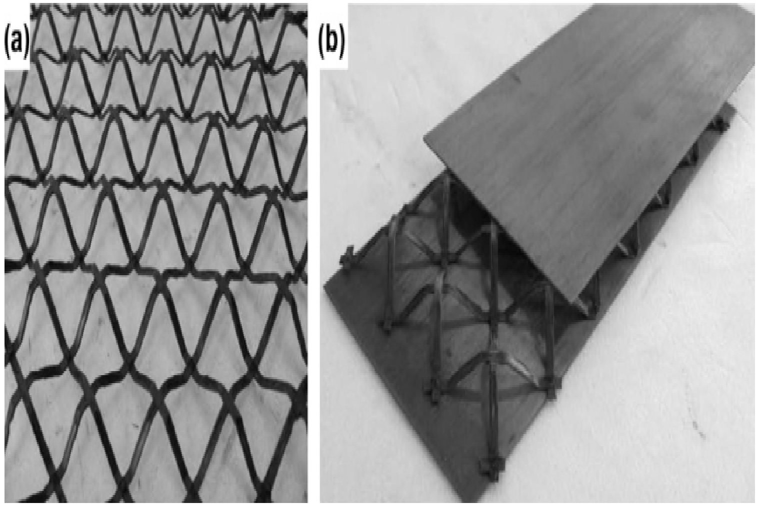
A new class of self-similar (fractal-appearing) hierarchical honeycombs with a wide range of elastic, plastic and load-induced expansion properties[1]

Bioinspired Surface and Interfaces



Bonded joints with non-flat interface design.





Fiber reinforced composite panels with lattice cores